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Confronting learning challenges in the field of maritime and coastal engineering: Towards an educational methodology for sustainable development

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ABSTRACT

This paper presents an integrated educational methodology to provide better, more extensive training to students in engineering disciplines. The methodology integrates both existing and ad hoc tools to improve mainly the following skills: holistic and comprehensive views of real problems, working in teams, communication abilities, and handling advanced numerical models and scientific computing. Experience by the authors with the implementation of the proposed methodology revealed a significant increase in the motivation and participation of the students: the more aware of the learning process they are, the more confident and motivated they feel. The implemented tools also help trigger student awareness towards a multidisciplinary, integrated and sustainable approach to face engineering problems, facilitating receptiveness to *working with nature* strategies. This methodology was developed for the field of marine and coastal engineering to overcome upcoming challenges such as problems due to climate change. Nevertheless, it can be easily extended to other engineering disciplines also pertaining to environmental problems and sustainability.

1. Introduction

In recent years, a shift has occurred in the role played by professional engineers; in addition to handling conventional engineering formulations, tools and procedures, current problems demand handling state-of-the-art technologies (El-Zein and Hedemann, 2016; Jones et al., 2017) and integrated approaches to achieve sustainable solutions that work with nature (De Vriend et al., 2015; De Schipper et al., 2016). The implications in education, at both graduate and master levels, are significant and involve new ways to provide students with the required capacities and skills (Halbe et al., 2015; De Andrade et al., 2016). The practice of professional engineering has a wide range of practical applications (Dean and Dalrymple, 2002; Ilzarbe et al., 2008). This requires teaching techniques and models that allow students not only to have a broad basis of theoretical knowledge but also to achieve the necessary skills to apply engineering principles and develop their careers (Perrenet et al., 2000; Woods et al., 2000). However, these facts collide with the excessive load of theoretical content that prevails in many schools, which in turn hinders student learning processes to some extent, often reducing their motivation (Huitt, 2001; Brophy, 2013). In addition, teamwork is not adequately encouraged in many educational settings (Dunlap, 2005; Goltz et al., 2008).

Classical approaches to practical teaching, such as the resolution of numerical exercises, are insufficient to provide students with a complete overview and understanding of problems (Viegas et al., 2016). These practical exercises are in many cases far from the programming routines and numerical models required to solve real environmental and engineering problems (Mathews, 1992; Chapra and Canale, 2012). At present, lifelong and project-oriented learning for engineers is considered fundamental (Naimpally et al., 2012; Leal Filho et al., 2016). However, companies must invest in practical training for their workers (Finegold and Soskice,

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1988; Noe, 2010), even immediately after incorporation. The learning process is therefore extended in terms of time, effort and money. Communication skills and critical thinking abilities are essential competencies for engineers concerning the safeguarding of life, property, economic interests, public welfare or the environment, among other things. However, those skills are not sufficiently well acquired by means of standard educational approaches (Lipman, 2003; Halx and Reybold, 2006). In non-English-speaking countries, students also have difficulties communicating in English, thus representing an additional limitation towards integration in the global market (Ferris and Tagg, 1996; Miller and Endo, 2004). Given these facts, it is clear that some of the most widely used teaching practices do not guarantee the development of a proper engineering epistemology (Felder and Silverman, 1988; Felder et al., 2000).

A key factor in the learning process concerns the assessment methods; they must ensure that competencies and skills are acquired while encouraging student motivation. In many countries, assessment methods are commonly based on a final exam, which mainly provides a final mark on the subject. According to the experience of the authors in the field of maritime and coastal engineering, with exam-based assessments, students frequently do not focus on acquiring the necessary background and competencies but only focus on passing the final exam. This fact results in ineffective learning processes and unfair evaluations in many cases, since a unique test does not guarantee the efficient acquisition of the required skills (Gibbs et al., 2005; Arends, 2014). In the framework of the European Higher Education Area, the Bologna process pursues the improvement of some of the aforementioned shortcomings (Reinalda and Kulesza-Mietkowski, 2005; Uhomoibhi, 2009). Its implementation forced the redesign of curricula, subject content and teaching practices in both bachelors and masters programs (Heitmann, 2005; Kehm and Teichler, 2006; Mälkki and Paatero, 2015).

The aim of this work is to present an integrated learning methodology that achieves the following objectives: (1) to implement as a learning tool the methods applied by companies to handle engineering problems providing sustainable pathways, (2) to encourage teamwork as well as improve the communicative and critical thinking abilities of students, and (3) to provide a flexible and multi-task-based learning process. To date, the methodology has been implemented in both the Bachelor Degree Program in Civil Engineering and the Master Program in Environmental Hydraulics at the University of Granada. The purpose of these teaching methods, which are feasibly extensible to other branches of education, is to bridge the gap between academic background and the labor market.

This paper is structured as follows. Section 2 synthesizes the main findings of previous works on education for sustainable development. Section 3 describes the implementation, evaluation and observed results of teaching methods. Section 4 discusses how this work ties in with previous studies. The conclusions based on early results and the novel contribution of the work to the existing body of knowledge are detailed in Section 5.

2. Literature review

Sustainability has received increasing attention in management education over the past few years (Figueiró and Raufflet, 2015). Thus, integration of sustainable development in education has been addressed in numerous educational institutions across the world. Based on different integration approaches, various teaching methods have been developed, applied and evaluated (Anand et al., 2015).

Azeiteiro et al. (2015) assessed the effectiveness of education of sustainable development through e-learning in higher education based on the expectations and experience of students. They concluded that formal e-learning programs can provide an effective alternative to face-to-face training, allowing students to pursue their studies in a flexible, collaborative and interactive way while holding down full-time jobs. Halbe et al. (2015) found that group model building exercises provide students with important experiences regarding stakeholder interaction, whereas the influence of curriculum planning and its implementation on the corresponding teaching structures and student experiences was demonstrated by Mälkki and Paatero (2015).

In the field of environmental and engineering education, De Andrade et al. (2016) developed a theoretical proposal to implement and monitor environmental education programs in universities. El-Zein and Hedemann (2016) highlighted that the focus by engineers on problem solving limits their ability to tackle root causes of social and environmental issues in technologically advanced societies. To face this limitation, Leal Filho et al. (2016) presented project-based learning as a tool to support integrative approaches to sustainability in a higher education context, while Jones et al. (2017) proposed that embedding sustainability in daily engineering practice has to evolve at the professional level by making sustainability part of formal engineering curricula.

To evaluate the course content knowledge and perceptions of students regarding overall course, content, and instruction methods, qualitative (focus groups) and quantitative (surveys) techniques were used before and after courses by Sharma et al. (2017). These evaluations give insight as to the extent to which sustainability is integrated into higher education study programs (Stough et al., 2017). Other valuable studies on education for sustainable development have also been conducted over the past few years (e.g., Disterheft et al. (2012, 2015), Figueiró and Raufflet (2015), Ramos et al. (2015), Cupido et al. (2016), Dlouhá et al. (2017), Holgaard et al. (2016), Staniškis and Katiliūtė (2016), Viegas et al. (2016) or Ismail et al. (2017)).

However, from the standpoint of the formation of scientifically skilled yet critical minds, the last stage of the process concerning higher education requires a combination of facts that, unfortunately, are still not consolidated in most teaching methodologies. To the best knowledge of the authors, learning practices to combine and enhance a comprehensive view and understanding of the problem, teamwork, transmission of knowledge and communication, and programming and computer capacities have not been implemented. In this context, the authors aimed to develop an integrated learning methodology, which consists of the joint implementation of a wide variety of techniques focused on the training of these four skills (Fig. 1). Although the implemented methodology was applied for maritime and coastal engineering specific themes, these tools can be easily expanded to other fields of sustainable engineering. The development of the methodology, the manners of evaluating its efficiency and some early results are detailed in the following section.

3. Methodology and first results

The methodology proposed in this work is based on dealing with real problems at the classroom-based level, enhancing communicative and critical skills to improve student personal development, applying standard e-learning tools, and assessing previously integrated elements.

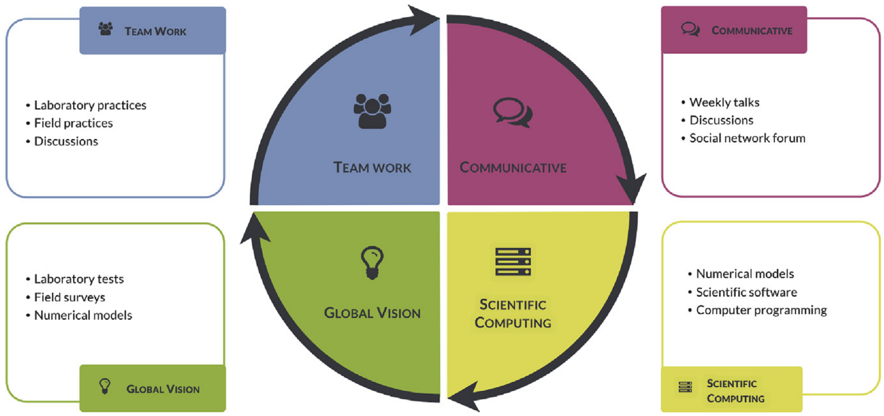

Fig. 1. Schema of teaching practices and competencies to be promoted.

3.1. *Bringing real engineering problems into the classrooms*

3.1.1. *Laboratory tests and field surveys*

Considering the academic education framework, it is necessary to prepare the scenario for laboratory tests and field surveys intended as practical lessons. These practical lessons are a straight way to introduce the learning traineeship usually applied by companies in the field of maritime and coastal engineering into the class dynamics. Indeed, the practices are organized through work teams and are based on a distribution of objectives, tasks and responsibilities among the team members to cope with the final goal of the proposal. This structure enhances teamwork, individual responsibility and horizontal knowledge transfer. Fig. 2 represents a schema on how the practice development is conceived.

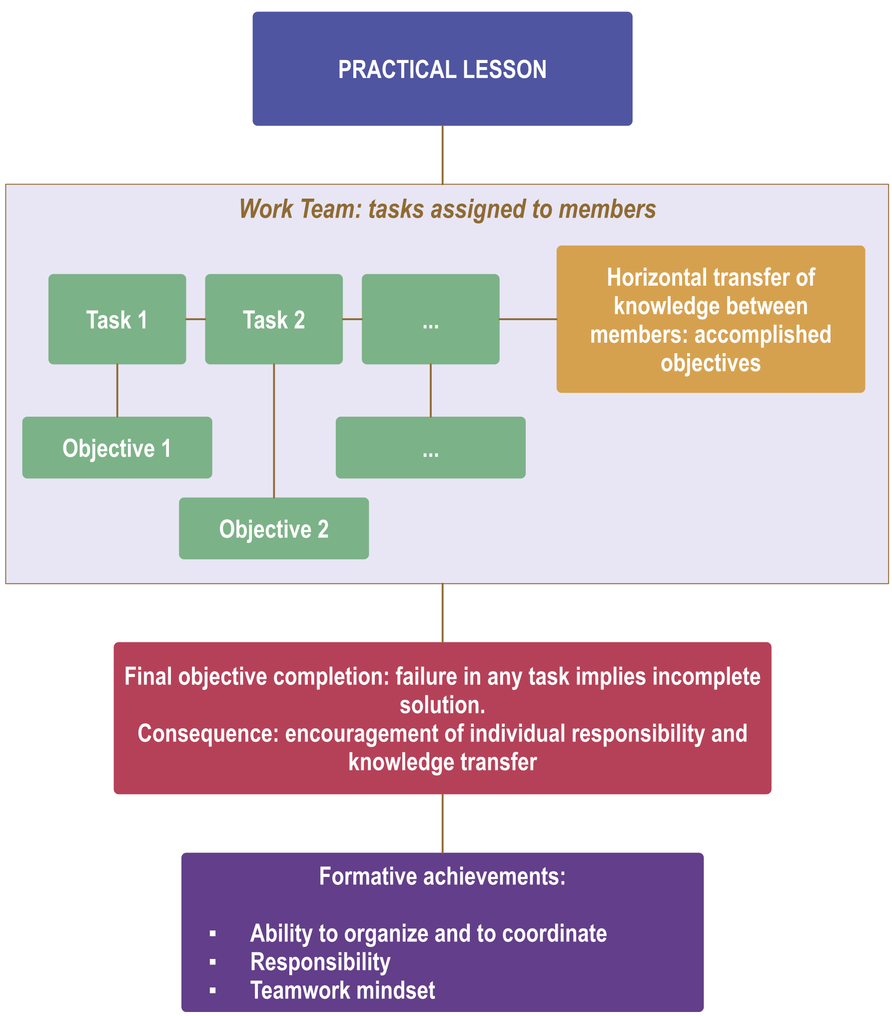

Fig. 2. Conceptual structure of the practices.

Fig. 3. (a) Laboratory practical lesson, (b) laboratory test in the wave basin, (c) field practical lesson on the boat, (d) hydrodynamic measurements on the boat, (e) practical lesson on the beach in the framework of a Summer School.

The laboratory practical lessons, conducted in the wave flume and wave basin (Fig. 3a and b), provide a controlled scenario in which physical processes and technical solutions to engineering problems are tested (Bergillos et al., 2017a). During the practices, the students (1) become familiar with the use of the lab instruments (e.g., wave gages, pressure transducers, laser Doppler velocimeters or high-speed cameras) and carry out different measurements (e.g., surface elevation, pressure and overtopping), (2) become familiar with the methodology to build up an experimental setup in which the main features in project solutions are represented, and (3) analyze the collected data with the goal of discovering relevant information using scientific computing tools, such as Python, R or Matlab.

Field practical lessons are used to identify and measure the fundamental variables governing physical phenomena. Special attention is also given to understanding the implications of the expected accuracy of these measurements. The field surveys vary from topographic, sedimentary and atmospheric measurements on the beach to hydrodynamic and bathymetric measurements on a boat (Fig. 3c and d). For this purpose, a wide variety of instruments are used: topographic stations, differential GPS, weather stations, acoustic Doppler current profilers and multi-beam echo sounders. Recorded data are used to apply and calibrate advanced numerical models, as shown in Section 3.1.2.

The results of these lessons, as demonstrated by personal feedback from students and the results of opinion surveys (Table 1), have revealed that students have a strong interest in both instrumentation usage and data post-processing procedures. The practices allow students to link theoretical concepts with practical solutions to real engineering and/or environmental problems. Once that conceptual link is settled, other further theoretical concepts are achieved in a more efficient way, providing students with a deep vision on how to approach real problems (Fig. 1) and what type of sustainable solutions may be planned.

This methodology is also applied in the framework of degree final projects, master theses and doctoral theses, resulting in an improvement in the quality of academic works and their associated scientific publications. As a recent example, it was successfully applied in the framework of a Summer School intended for MSc and PhD students (*Estuarine and Nearshore Systems: From Fundamentals to Cutting-Edge Knowledge*) in June 2016 (Fig. 3e). The results of the evaluation survey completed by students after the Summer School are shown in Fig. 4.

3.1.2. Workshops with advanced numerical models

Most of the problems and projects in the field of civil engineering, in general, and of maritime and coastal engineering, in particular, require the application of complex formulations and/or advanced numerical models. However, these approaches are commonly excessively complex to be addressed by undergraduate students.

Several efforts have been made over the last decade to develop graphical user interfaces (GUIs) that allow modeling, without any simplification, physical processes such as wave refraction, shoaling

Table 1
Average ratings and standard deviations of the student opinion surveys for the subjects in which the methodology was applied, for all the subjects of the degree and for all subjects of the university.

	2012/2013	2013/2014	2014/2015	2015/2016
Subjects average rating	4.25	4.29	4.42	4.63
Subjects standard deviation	0.52	0.59	0.57	0.48
Degree average rating	3.54	3.61	3.76	3.75
Degree standard deviation	1.07	1.1	1.13	1.19
University average rating	3.8	3.83	3.9	4.12
University standard deviation	1.12	1.12	1.15	1.03

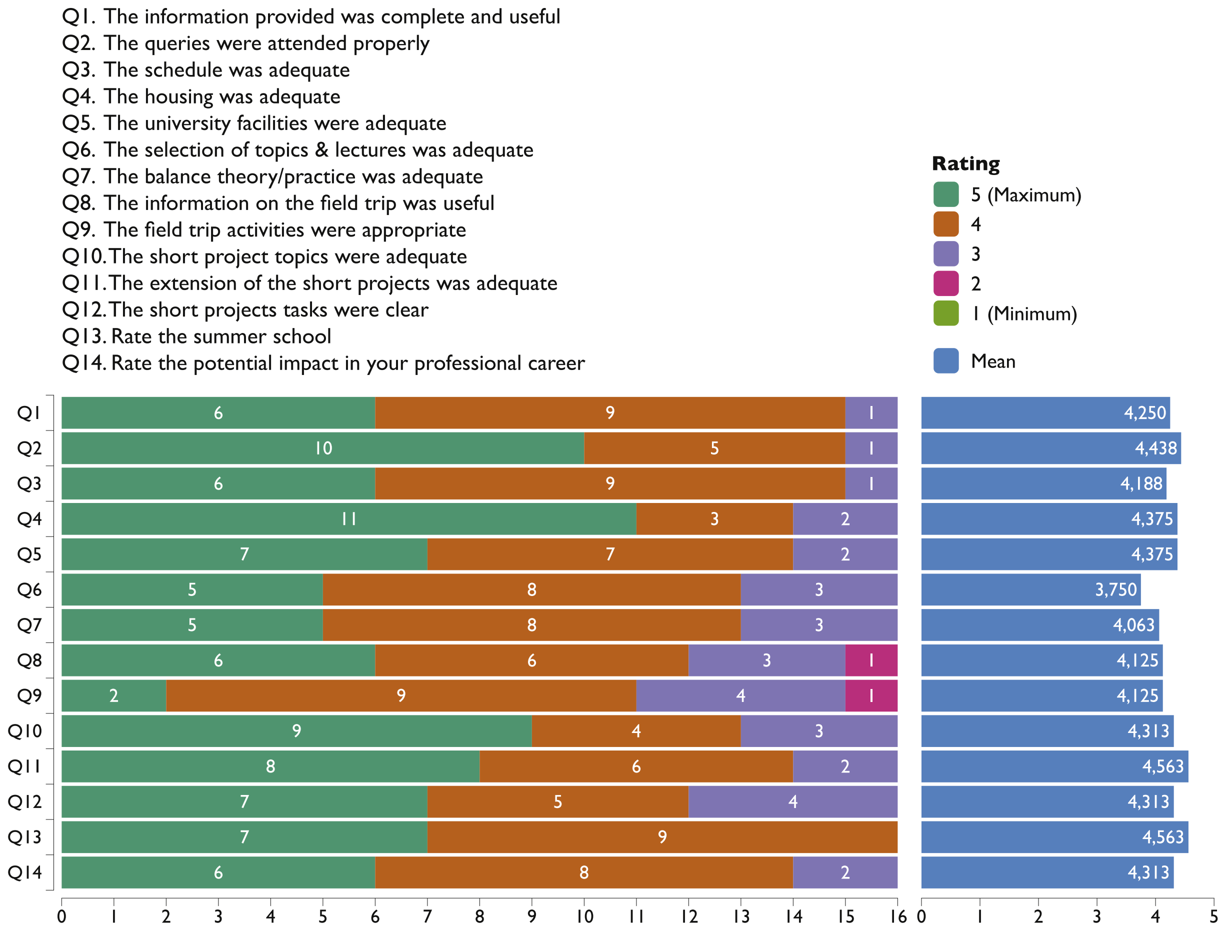

Fig. 4. Evaluation survey of the Summer School: questions and results.

and breaking, or coastal erosion and sedimentation. Some examples are the Delft3D (Lesser et al., 2004; Lesser, 2009) or XBeach (McCall et al., 2014, 2015) models. The implementation and calibration of these models is taught to solve real engineering and environmental problems in workshops for undergraduate and master students.

Nevertheless, to the knowledge of the authors, there are no GUIs available that simulate more complex approaches used to design sustainable solutions, such as wave climate simulation (Solari and Losada, 2012a, b) or wave downscaling (Camus et al., 2011, 2014). For this reason, specific ad hoc user-friendly applications were developed with Matlab that allow students to reproduce these techniques (Bergillos et al., 2017b). The use of these applications is also taught during practical lessons.

Students have shown in opinion surveys that they feel motivated by these workshops and have improved their programming and numerical capabilities. This learning mechanism, in combination with the experimental practices (Section 3.1.1), allows student to develop a global vision and understanding of the problems (Fig. 1). They analyze the results in detail and show an increasing interest in their applications in the decision-making process; that is, they acquire the required skills in an effective manner.

3.2. Improving the communicative and critical skills

3.2.1. Weekly talks on current engineering topics

From the experience of the authors, the background acquired by the students contrasts with the comparatively weak ability to transmit not only their knowledge but also their technical opinions. These communicative skills are essential to address technical issues of sustainability problems, since these issues require integrated, adaptive and participatory approaches (Halbe et al., 2015).

For this reason, the authors incorporated weekly talks as a learning mechanism, in which students present engineering news in an enthusiastic and convincing way to their classmates. The talks are given in English (non-native language). After the presentation, the rest of the students and the teacher discuss the topic, give opinions and provide feedback to the speaker, focusing not only on the technical content of the presentation but also on the nonverbal language, the design and utilization of the support material (e.g., PowerPoint, images, videos, etc.), and the role played by the presenter. Some presentations are recorded to analyze the nonverbal language, provide tips based on these analyses and evaluate student progress.

According to the observations, personal feedback of the students and video recordings of the talks, communicative skills, reciprocal learning between students and the general classroom atmosphere have improved over the early years. The improvement in communicative skills has occurred not only within the scope of talk content, since students now have a greater willingness to raise questions about the organization of lectures, negative aspects that could be improved and positive ones that should be reinforced. For future courses, real cases in which people from companies assist to correct, give opinions and offer feedback to the students are being planned.

3.2.2. *Discussions on real management problems: role-playing*

To improve communicative skills as well as arguing, interacting and discussing techniques, periodic debates about real management issues were implemented. Students are divided into groups of two or three people, and each group represents one of the agents (administrations, institutions, companies, stakeholders, associations, etc.) involved in the problem.

Fig. 5 represents an example regarding the sustainable management of deltaic areas from the points of view of scientists, coastal managers, basin managers, local governments, fishermen, farmers, tourist companies, ecologists and stakeholders, based on the *Imagine* methodology (Jude et al., 2007; Bell, 2012). For the project of maritime works, the roles of consulting, construction and shipping companies are also included.

These role-playing practices guarantee not only the acquisition of competences by students but also training to express arguments, defend ideas and interests, and discuss them with other interlocutors. The capacities of communication, dialog, empathy and teamwork are directly reinforced (Fig. 1). These discussions are also presented in English to improve student usage.

3.2.3. *Social network forum*

Currently, students spend a great deal of time on the Internet, especially on social media (Grohol, 1999; Emanuel et al., 2008). Therefore, social media are also tools for educational and learning purposes (Liu, 2010; Junco, 2014). In this context, although universities provide their own platforms for learning and interaction with students (e.g., Moodle, Blackboard or Sakai), the authors administer a Facebook page whereby teachers and students ask and answer subject-related questions, exchange technical and scientific information, share engineering news, etc. Surveys about different subjects have also been conducted through the Facebook page.

The participation of the students on the page is remarkable; there are new entries almost every day. Furthermore, in the several years since implementation, the page is being used for professional environmental and engineering purposes: old students request and offer jobs, ask and answer work-related questions, share professional experiences, ask for advice, etc.

3.3. *E-learning as a means of bringing engineering further away*

E-learning in higher education can be of great relevance in effective life-long learning education for sustainable development in a population of students who are simultaneously full time employees (Azeiteiro et al., 2015). Recently, there has been an increase in the number of people who cannot attend regular classes at a university due to a wide range of reasons, such as economic difficulties to move from their home cities or problems in combining studies with work and/or family life (Lucas and Lammont, 1998; Robotham, 2009; Azeiteiro et al., 2015). For this reason, the authors deployed a web platform by means of the *AdobeConnect* software program, which allows students to receive real-time online teaching and interact with both the teacher and classmates. The platform has the following three tool windows: (1) live images and audio of the teacher, (2) content displayed on the class computer, and (3) a chat area for consultation and transfer of information among classmates, and between the teacher and the students (Fig. 6).

In addition, an integral e-learning platform including audiovisual teaching material (with transcripts) was created. This material is available for streaming and is compatible with most current mobile devices (laptops, tablets, smartphones, etc.). Students can upload their tasks and practices to the web platform, which also has an automatic correction system including plagiarism control.

From the perspective of the students, these platforms facilitate learning the subject contents in a more flexible way; for the university staff, the platforms allow keeping track of students, correcting tasks and providing feedback faster, simpler and in a more enriched manner.

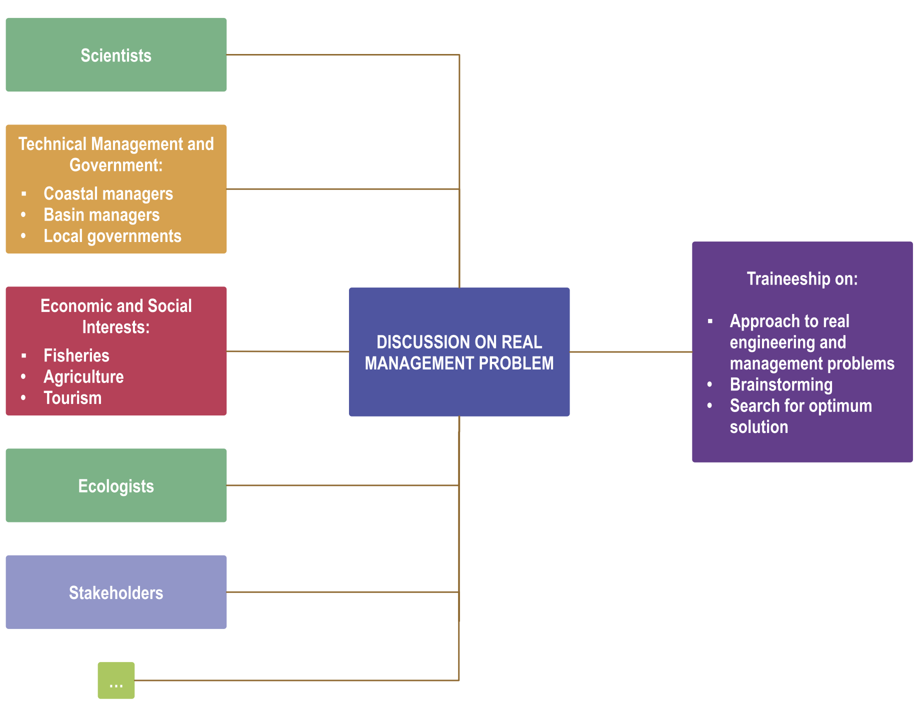

Fig. 5. Conceptual structure of the discussions.

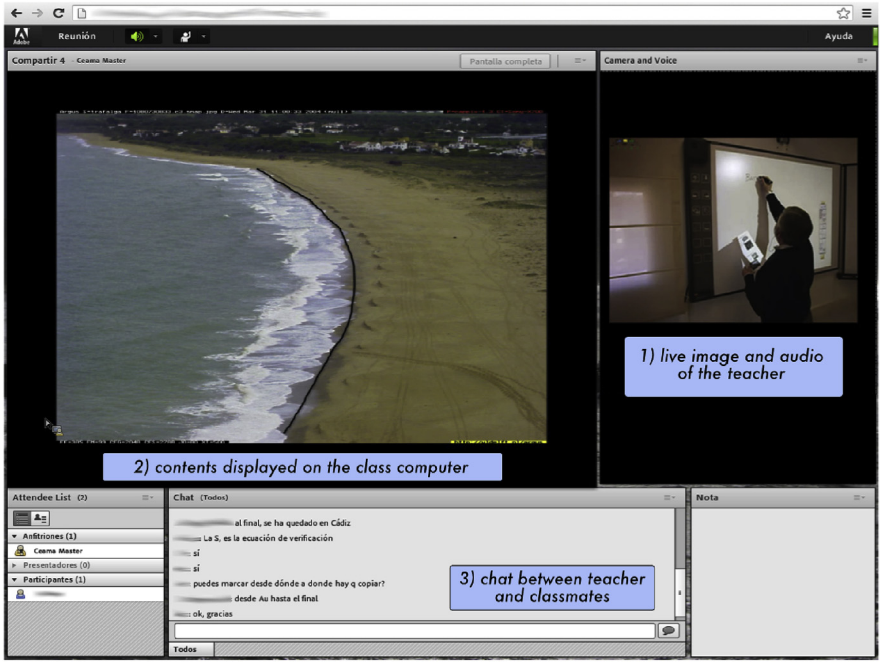

Fig. 6. Screenshot of the deployed web platform for real-time online teaching.

3.4. Assessment based on a wide variety of practical tasks

This learning methodology allows assessments based on multiple and varied tasks, which are carried out progressively. In this way, the joint volume of work is greater than with a single exam, but the learning process takes place in a more gradual, ordered and efficient manner. Students have the option and right to choose a final exam assessment.

Students motivation and willingness to work have increased since the implementation of this assessment methodology. As a result, a clear improvement in competency acquisition has been observed. The final marks have also been enhanced accordingly (Fig. 7). This could be attributable to the effectiveness of the implemented methodology and/or to the new evaluation system (based on the joint assessment of all the tasks detailed in this section) since its implementation, among other possible causes.

4. Discussion

Until recently, among the engineering disciplines, education has essentially focused on the design, construction and maintenance of infrastructures (Zhang et al., 2017). Most attention was generally paid to constructive procedures with the safest criteria, keeping the costs low (Frangopol and Liu, 2007). However, present and upcoming challenges for engineers are progressively turning towards sustainable management of environments and working with natural solutions to minimize impacts (Van Slobbe et al., 2013; De Schipper et al., 2016). Engineering problems are turning into complex decision-making processes in which different disciplines should interact to provide sustainable management solutions (Félix et al., 2012; García-Morales et al., 2015). Furthermore, societies demand professionals with the background and skills necessary to enhance the sustainability of long-lived infrastructure to cope with climate change risks (Neumann et al., 2015). The proposed educational methodology combines a wide range of teaching practices to enhance a comprehensive understanding of the problems related to sustainable development and the integration of professionals into multidisciplinary teams.

As discussed in this work, during recent decades significant technical breakthroughs have been made regarding possible engineering education tools. From numerical models (e.g., Liu (2010) or Vilela et al. (2017)), web-based platforms and digital and social media (e.g., Liu (2010) or Junco (2014)) to laboratory experiments (Feisel and Rosa, 2005; Balamuralithara and Woods, 2009) and project-based learning (Mills and Treagust, 2003; de Los Rios et al., 2010), the range of possibilities for faculty members has increased significantly. In addition, in countries such as those in the European Union, there has been an intense effort to unify this process whenever possible (e.g., Erasmus programs or the Bologna process). Despite these efforts, graduating students (including masters degree students) must face the global market with a clearly defined set of capabilities and skills that include not only the ability to resolve conventional engineering problems and cope with engineering projects and situations, but also communication, networking and the ability to work in teams.

5. Conclusions

This paper addresses the implementation of an integrated methodology to improve student learning in dealing with the complexity of management problems in the field of maritime and coastal engineering. The main contribution of the methodology to the existing knowledge is the joint implementation of different teaching methods that determine solutions to largely observed issues concerning skills in engineering education, such as communication and critical capacities, ability to work in teams, programming and computer capabilities, and comprehensive view of the problems; which have all been comparatively poorly trained within traditional learning approaches. Some of the applied tools are now frequently used by both undergraduate and graduate students, whereas others have been specifically designed for this purpose and presented in this work.

The implemented methodology is capable of coping with many of the following challenges that are presently facing engineering

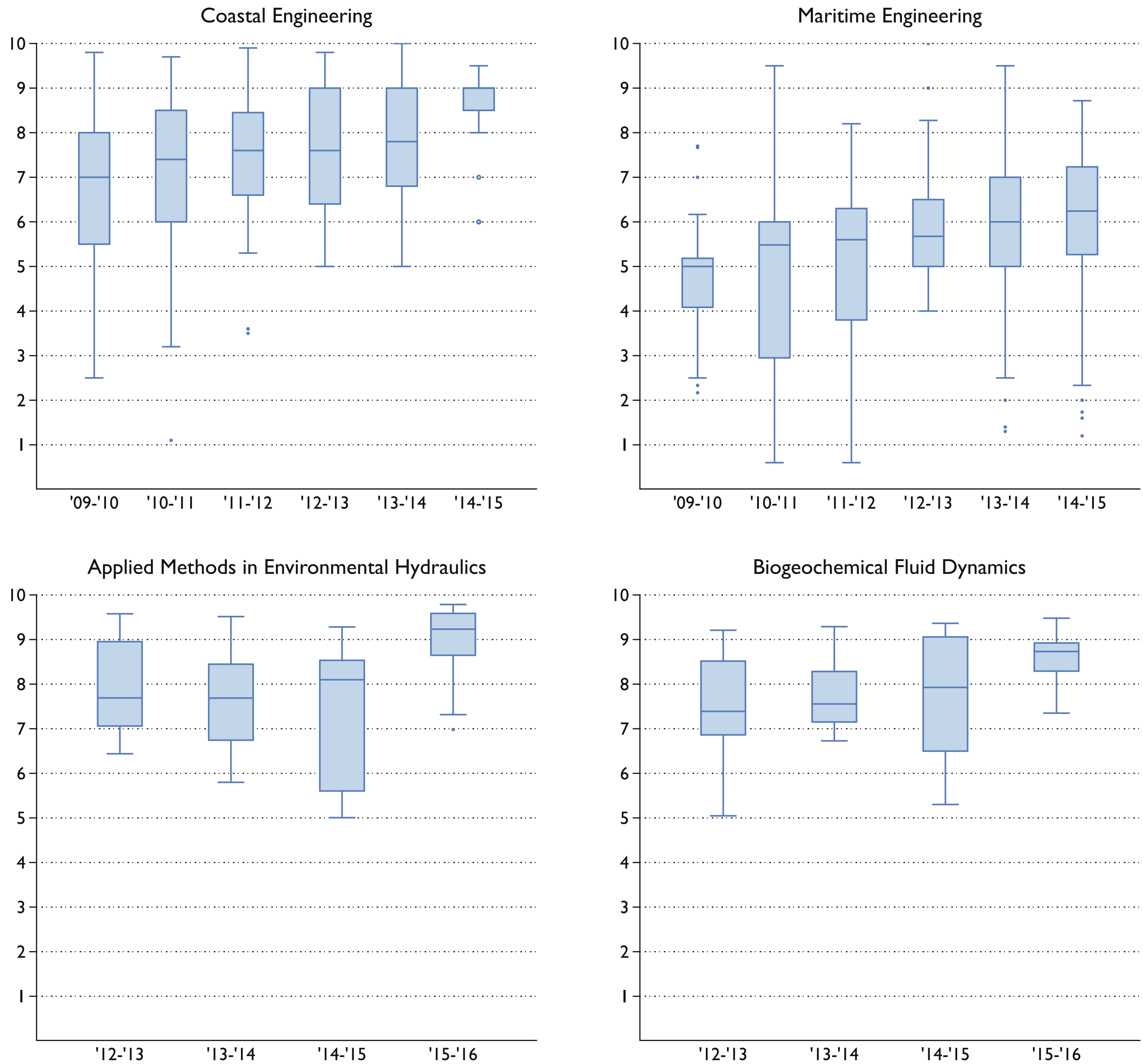

Fig. 7. Final marks of the subjects since the implementation of the methodology. Upper panels: Coastal Engineering and Maritime Engineering (Bachelor Degree Program). Lower panels: Applied Methods in Environmental Hydraulics and Biogeochemical Fluid Dynamics (Master Program).

education: (1) a global market where engineers are working in different countries (language and social skills), (2) the complexity of real engineering problems with strong social and environmental implications, where multidisciplinary approaches are mandatory and where third-party interests are involved, and (3) the use of the latest state-of-the-art technologies. The reported teaching methods also help trigger student awareness towards a multidisciplinary, integrated and sustainable way of addressing real engineering problems. The methods were implemented over the last decade in both bachelor and master's degree programs with a high degree of success, resulting in a valuable progress within education for sustainable development.

These teaching methods can be extended to other educational contexts. For that, the practical lessons, numerical models or tools, weekly talks and role-playing practices should be adapted to the specific branch. For example, the adaptation to health education would require practical lectures on real problems in a hospital, workshops with specific software used by professionals, talks about health news, and discussions on diseases and diagnostics, among others. Similarly, in the field of law, practical lessons about real situations in trials, talks on court ruling, and role-playing practices including the roles of judges, district attorneys and lawyers would be advisable. Other teaching techniques, such as e-learning and assessments based on a wide variety of practical tasks, are directly extensible to other contexts.

The methods and results presented in this paper represent a step forward, but sustainable education will face some stimulating challenges over future years. In the context of maritime and coastal engineering, *working with nature* solutions will be required to help mitigate or adapt to the expected implications of climate change on coastal areas around the world. These nature-based solutions imply that project objectives should be first considered from the

perspective of natural systems; understanding the way natural processes work in the environment and how to cope with them to maximize opportunities and reduce negative impacts and costs is fundamental. In addition, the integration of upcoming advances in scientific computing and the capability of big data for the design of sustainable solutions in classrooms and workplaces will be additional challenges to be addressed in the coming years.

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